TM-933
2125.000

Fermilab

Program SHOTAM. Simulation of Supershowers for Calorimeter Design and Analysis

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January 1980

Introduction

The program SHOTAM is a modified analog Monte Carlo code to trace and analyze hadronic showers in large targets. It is intended mainly to serve high energy physics experiments e.g. design of a calorimeter. The physical model is much the same as that of the program CASIM[1]. The significant changes are outlined below. An earlier more limited version of this work was briefly mentioned elsewhere.[2] Extensive comparisons with experiments have not as yet been performed. A limited comparison (not included here) with data of Barish et al.[3] in the range 5-250 GeV is in good agreement.

This report concentrates on the special features of the program of interest to potential users. The computation generally proceeds in two stages. First, a record of a set of simulated showers is generated and written on a magnetic tape, or other recording device. In the second stage these records are analyzed by another Monte Carlo program which simulates the response of one or more detectors (typically placed at regular intervals within a large target).

Supershowers

Even for a powerful computer a thorough analog simulation of a high energy shower is quite time consuming. This is partly the reason for going through the intermediate step of recording the shower. A further time-saving device is to generate "supershowers", defined as showers in which no π^o are present. Such a supershower results when during simulation of an ordinary shower each predicted π^o is reassigned a charge. The charged pions thus generated along with any progeny are then traced the usual way. (It is noted in the record whenever a reassignment occurs. Thus the ordinary shower underneath the supershower can always be recovered.) The savings in computer time are obvious: when the SHOTAM tape is analyzed the charge of each pion member of the supershower may be randomly assigned. For example, a simple routine is (i) with constant probability ($\simeq 1/3$) let any <u>produced</u> pion be neutral and assign alternate charges to the charged pions produced in the same collision, (ii) <u>leading</u> pions as well as pions which suffered an elastic or quasi-elastic collision keep their assigned charge. More sophisticated algorithms are derived from correlations between neutral and charged collision products observed in bubble chamber experiments. (Some of these are included in the basic showers of SHOTAM upon which the supershowers are built.) In this manner one single supershower may be used repeatedly. The response of a calorimeter or similar device is strongly influenced by the way the incident energy is divided among the hadronic and electromagnetic components. Hence while some correlations will remain among a set of showers derived from the same supershower these can be largely ignored. The validity of this has been verified in the particular example of estimating the resolution of a proposed liquid argon calorimeter[4].

A further advantage of the supershowers is the ability to concentrate on rare classes of events. By systematically altering the charge assignment probabilities in the analysis (and thereby incurring compensating weighting factors) very unusual events can be generated e.g. all (or nearly all) neutral pions. In this manner a sample of events may be generated which, while very atypical of hadron showers, constitutes an important difficult-to-cut experimental background.

A third advantage is that a set of supershowers permits the study of the energy division between hadronic and electromagnetic components and its effect on a particular experimental design in a highly correlated fashion. This tends to minimize the noise inherent in comparing independently generated Monte Carlo events.

The notion underlying the supershower concept may be generalized to other modifications besides charge reassignment. The types of modifications will depend upon the specific application e.g. the pathlength between collisions of neutrons (and to some extent also high energy charged particles) could be altered to study leakage effects on calorimeter resolution. While such modifications tend to complicate the coding and computation and possible cloud interpretation of results they offer a reasonable alternative where direct analog calculation is too slow.

Physical Model

The physical model is largely the same as in the code CASIM[1]. The basic particle production model is that of Hagedorn and Ranft[5] supplemented by a high transverse momentum component[6] as well as by a source of low energy nucleons as described by Ranft and Routti[7]. In addition a certain amount of nuclear excitation energy is created in each nuclear collision. Elastic scattering and ionization losses are included.

A few basic changes are made in the particle production model.

In the present treatment the high energy part of the collision in a complex nucleus is assumed to take place between the projectile and a number of target nucleons. This number (which may be larger than unity in contrast with the model in CASIM is chosen from a Poisson distribution truncated at the mass number with an average determined from simple geometric considerations. Each such nucleon is emitted from the collision as a leading (target) particle. A second added feature is inclusion of charge exchange since this is likely more important in calorimetry than in the typical CASIM application.

The present program differs from CASIM principally in the analog mode of simulation. This permits energy to be conserved rigorously in each collision. In the high-energy part of the collision charge is conserved (±one unit) and momentum is conserved exactly. In the low-energy part this is only approximately enforced.

The distributions from which a particle's momentum is chosen are inclusive distribution. Therefore, with a few exceptions noted below only those correlations arising from conservation laws are present. Also, enforcing these conservation laws will lead to the eventual rejection of a selected momentum. This problem is treated in the manner of Ranft[8] by storing the weight of the rejected particle in a large array for future reference. Entires in this array are binned according to incident momentum, outgoing transverse momentum, outgoing center-of-mass longitudinal momentum as a fraction of its maximum value and particle distribution type.

The program computes the remaining invariant mass following emission of each high-energy collision product. When this invariant mass becomes less than 1.3 GeV it is assumed to decay into three pions and below 0.9 GeV into two pions. Below 0.35 GeV it is treated invariant mass. Like the kinematically rejected particles these decay pions are stored in the array (but with negative weight) until a particle with similar characteristics is selected from an inclusive distribution. Then the stored particle is expunged and a new inclusive particle is selected.

The inclusive distributions used in the present program are not expressly written for ease of random sampling. In non-analog computations a simplified selection scheme is used and the selected particle acquires a compensating weight. SHOTAM proceeds likewise and the surplus or deficit weight (with respect to unity) is retained in the aforementioned array. Below some minimum weight (presently set at 0.25) the particle is rejected and its weight stored[9]. No serious attempt has been made to optimize this bookkeeping scheme.

Magnetic Tape Record

The type of information to be preseved for analysis will vary with each problem. The following set is suitable for analysis of calorimeter response. Where more (or less) information is desired this can readily be modified. There are five occasions during the Monte Carlo when a record is written on the tape (i) when a particle undergoes a collision, (ii) when a particle falls below threshold, (iv) after each incident particle and (v) at the end of the calculation. Each such record has the same format. The record for a collision contains generation number, particle type (including whether leading or produced particle and for pions whether directly selected or via charge reassignment), collision type (i.e. inelastic, elastic, quasi-elastic or charge exchange), target nuclear species, coordinates of location and momentum of the projectile at its origin and at collision, nuclear excitation energy following collision. The other types of records contain similar information.

The program is capable of treating arbitrary geometries, heterogeneous media and magnetic fields. These features are of interest primarily for studies of existing equipment or final designs. In the early stages it is easier to create a record for a single homogeneous medium (of atomic mass and atomic number approximately averaged over the various components). Most properties of hadronic cascades are not very sensitive to atomic mass. If hydrogen is present in significant amounts a two-component calculation might be worthwhile from the start. The presence of gaps can be simulated to first order by rescaling distances between events.

Analysis

The second stage of the program reads the tape and (i) derives one or more (possible weighted) ordinary showers from each supershower and (ii) translates the records of the ordinary showers into the response of a set of detectors. Certain aspects of the analysis also involve Monte Carlo simulations e.g. electromagnetic showers and neutron detection. In general the part of the program pertaining to detector response should be user supplied. Analyses for plastic scintillator and liquid argon have been performed although not at the highest possible level of accuracy. The simulation of π^o initiated electromagnetic showers starts from a prescription for the average energy deposition[1]. This assumes that the energy is deposited according to a (properly scaled) universal distribution function of distance along the shower and angle with the shower axis. A crude analog version runs as follows: (i) the π^o decays into two photons which in turn each create two electrons, (ii) each electron deposits its energy along a number of rays according to the above prescription, (iii) each energy increment calculated to be deposited in a detector medium is converted by random selection into an integra number of singly ionizing particles via a Poisson distribution. The actual number of rays in (ii) varies with energy and is such that the number of integral increments of (iii) is always small. The justification for this rather crude procedure is that for most situations fluctuations due to the hadronic part of the cascade dominate. This is a consequence of the numbers of particles involved Where this is not justified more refined algorithms should be used based e.g. on the program AEGIS[10] or else resort to full analog simulations of electromagnetic showers[11]. Generally this will considerably increase computer time.

The nuclear excitation energy is divided among charged particles and neutrons according to a simple prescription. The charged particle energy is deposited locally. Simple algorithms are used to determine the number and energy of evaporation neutrons as well as their transport. The simulation of energy deposition by low energy neutrons in plastic scintillator uses basically the code of Stanton[12]. The saturation effect of energy deposition by heavily ionizing particles in scintillator is also included[13].

References

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